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THE 1974/75 STRATOSPHERIC WINTER

By N. R. WATSON

SUMMARY

In August 1974 new definitions of stratospheric warming were proposed. These were used for the first time during the northern winter of 1974/75 by the Stratospheric Research Group at the Free University of Berlin in issuing STRATWARM alert messages. This paper describes the features of the stratospheric circulation in relation to the warmings of the winter. The examples of the circulation changes which occurred, mainly at 10 mb, were taken from the daily chart series prepared in the High Atmosphere Branch of the Meteorological Office at Bracknell.

Examples of the kinetic-energy changes and of the vertical motion in the stratosphere during warming periods are also presented.

THE STRATOSPHERIC-WARMING-ALERT SYSTEM

In November 1973 the Commission for Atmospheric Sciences (CAS) of the World Meteorological Organization (WMO) noted that adequate explanations of major stratospheric warmings were still not available and that the phenomenon had not been observed in sufficient detail. Although the stratospheric-warming-alert system had first been introduced during the International Year of the Quiet Sun (IQSY) in 1964, and much information had subsequently been accumulated about the warmings, there remained many outstanding problems. It was considered that studies of stratospheric problems would benefit from a concerted effort to gather as much information as possible during all stages of the winter warming period. A new and improved alert system would allow investigators to schedule observations during the times of maximum scientific interest. Consequently a Rapporteur was appointed by the CAS working group on stratospheric and mesospheric problems to review the criteria for STRATWARM alert messages and the observational program required on receipt of such messages. The Rapporteur in question, Dr Karin Labitzke, of the Free University of Berlin, met a working party composed of interested workers at Wallops Station, Virginia in August 1974, and new criteria were proposed for use in the 1974/75 northern winter. It was agreed that the Stratospheric Research Group of the Free University of Berlin would initiate daily messages on the 10-mb circulation, and issue the alerts when appropriate.

The new definitions for the warmings were formulated as follows:

(a) A warming is called MINOR if there is a temperature increase of at least 25 deg in a week or less, observed by balloon-sondes or rocketsondes, or inferred by radiances measured from satellites, at any stratospheric level in any area of the winter hemisphere. Warmings which do not meet this criterion may be said to be local warmings.

(b) A stratospheric warming is said to be MAJOR if at 10 mb or below* the latitudinal mean temperature increases polewards from 60°N *and* an associated circulation reversal is observed (i.e. net mean easterly winds are established north of 60°N).

A STRATALERT would therefore be issued when temperatures rose over an area by at least 25 deg in a week or less. A GEOALERT/STRATWARM alert message would be initiated when the temperature rose at least 30 deg in a week or less at 10 mb or below, or at least 40 deg above 10 mb.

The 10-mb level was chosen as the key level because it was the highest that could be analysed daily at Berlin with any degree of confidence. It was assumed that maximum use would be made of satellite radiance data, for example from the Selective Chopper Radiometer (SCR) instrument on NIMBUS E, and a communications link was therefore established between Oxford, where the SCR data are processed, and Berlin. These data provided an 'early warning' of the subsequent warmings at 10 mb by detecting them at higher levels.

The daily alerts were issued by Berlin at 1400 GMT, received by the High Atmosphere Branch at Bracknell by about 1430 GMT, and then distributed to interested groups in the United Kingdom.

On receipt of a STRATALERT message concerning a MINOR or MAJOR warming, the various meteorological rocket stations throughout the northern hemisphere agreed to fire rockets at an increased rate. Firing rates of up to three times a week were thought to be necessary, depending on the location of the warm area in relation to the rocket station. The Metrocket Group of the High Atmosphere Branch at Bracknell fired a total of 22 SKUA rockets during two detachments to West Geirinish, South Uist, in December 1974 and January–February 1975. The rocketsonde observations (ROCOBs) provided information up to about 65 km, but only data obtained below about 30 km (10 mb) were used in the daily series of charts produced by the Stratospheric Analysis Group in Bracknell.

Stratospheric analysis

Daily charts of the northern hemisphere at 50, 20 and 10 mb for 00 GMT have been drawn by the Statospheric Analysis Group of the High Atmosphere Branch since April 1974. These charts are drawn from radiosonde data and, when available, ROCOBs, but no satellite data are used. The ROCOBs are very valuable in the determination of the wind field at 10 mb, and especially so over the polar cap, since few radiosondes reach that level during the winter. The paucity of observations at 10 mb means that it may be 10 days or more before an individual chart is completed and the analyst is confident that continuity of flow pattern has been achieved. It is from this series of charts, mainly at 10 mb, that the major features of the 1974/75 winter stratospheric circulation will be discussed.

*Here and in similar contexts throughout this paper 'below' is to be interpreted as meaning 'nearer to the surface of the earth' and not 'at heights corresponding to numerically lower pressures'.

10-MILLIBAR CIRCULATION CHANGES

(a) *Summer to winter*

The normal summer-time circulation above about 20 mb consists of a generally easterly flow round a warm anticyclone centred over the pole. The wind field near the equator is dominated by the quasi-biennial oscillation and in the summer of 1974 was easterly and about 60 kn at 20 mb, and was changing rapidly from easterly to westerly at 10 mb.

Figure 1 (adapted from Murgatroyd, 1970) shows the mean summer and winter zonal wind and temperature conditions to be expected.

The warmest air occurs at about 1 mb (47 km) over the summer pole, while at 10 mb the temperature is about −25°C at the pole, and decreases steadily to about −50°C at the equator.

In mid July 1974 the 10-mb anticyclone was symmetrically placed over the pole with a central height of 32 300 gpm and an easterly wind of 20–25 kn over the United Kingdom.

By late August the high had declined to 31 500 gpm and had moved to Alaska, as small cold pools began to appear in mid latitudes. The first sign of the polar vortex appeared in mid September near Novaya Zemlya, and it deepened and moved eastwards round the pole. By the end of September it lay over the Canadian Arctic at 30 480 gpm (−55°C), while the remains of the summer high were displaced across the Pacific and north-west Atlantic (−45°C).

Cooling continued during October with further deepening of the polar vortex down to 29 760 gpm in early November over Greenland and with temperatures falling to −68°C. During November the main low split and then reamalgamated with troughs swinging eastwards across Siberia and Alaska. It was late in the month when the Aleutian anticyclone became finally established after the eastward passage of such a trough into the U.S.A. By early December the 10-mb circulation reached its 'classical' winter state with a minimum height of 28 560 gpm near Novaya Zemlya, and a maximum of 31 080 gpm over the Aleutian Islands. The coldest air, −75°C, lay just to the west of the vortex, with the warmest air (−35°C) over China and Kamchatka (Figure 2).

(b) *Early winter warming*

The first minor warming alert was issued on 14 December when temperatures over southern Europe rose to about −25°C. Figure 3 shows the changes in the temperatures at 30, 20 and 10 mb during the period 10–19 December 1974 at Vienna. The 10-mb temperature rose 35 deg in about four days and then fell back to its original value; the 20-mb temperature showed only small fluctuations while the 30-mb temperature change was in the opposite sense to that at 10 mb. The cause was a temperature wave that crossed the Atlantic from the Caribbean and then moved farther east into Asia. As this warm wave was moving east over the Atlantic, the 10-mb trough over Canada was intensifying so rapidly that from 8 to 15 December it developed into the major low as it moved from the Canadian Arctic north-eastwards to Spitsbergen. The original low which at the beginning of the month was near Novaya Zemlya degenerated into a trough which weakened rapidly as it rotated eastwards.

These rapid changes at 10 mb were probably indicative of much more violent changes in the middle and upper stratosphere. On 13 December the rocketsonde observation at West Geirinish showed a belt of extremely strong wind at 55 km;

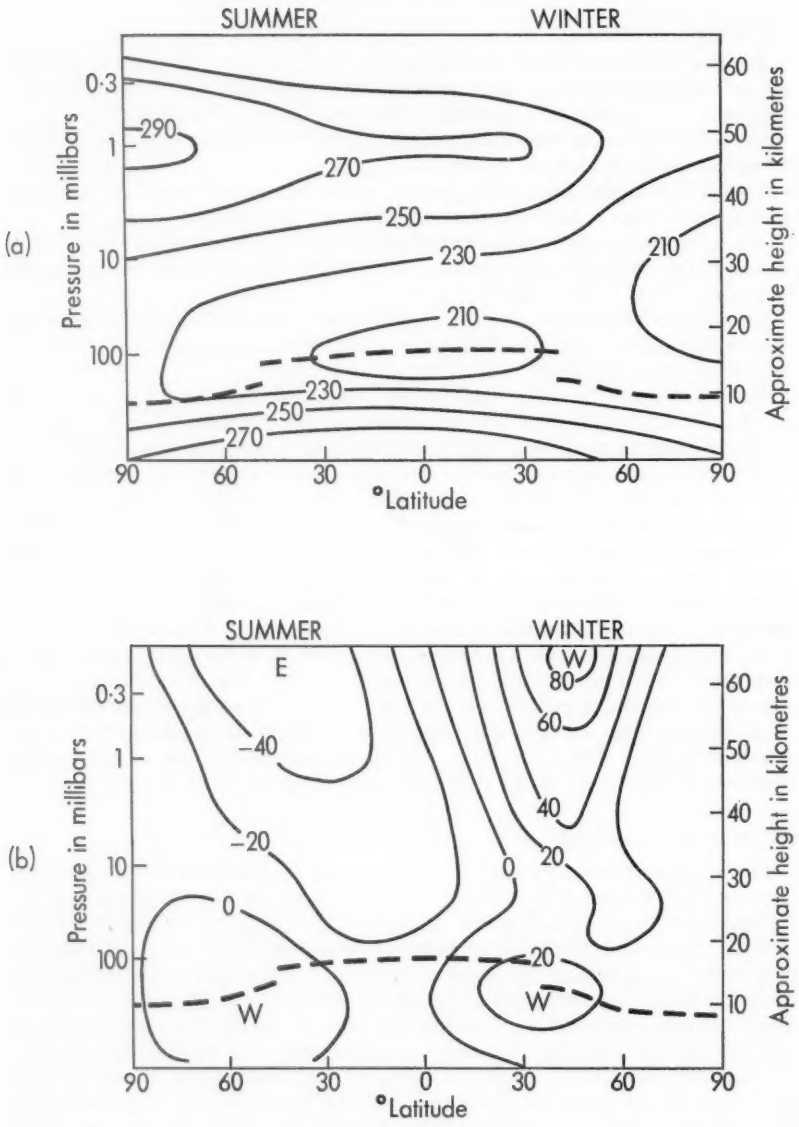

FIGURE 1—LATITUDINAL MEAN CROSS-SECTIONS OF TEMPERATURE IN KELVINS (a) AND ZONAL WIND SPEED IN METRES PER SECOND (b) FOR THE SOLSTICES
The thick dashed lines represent the tropopause. In the lower diagram E denotes 'easterly' and W 'westerly'. (Adapted from Murgatroyd, 1970.)

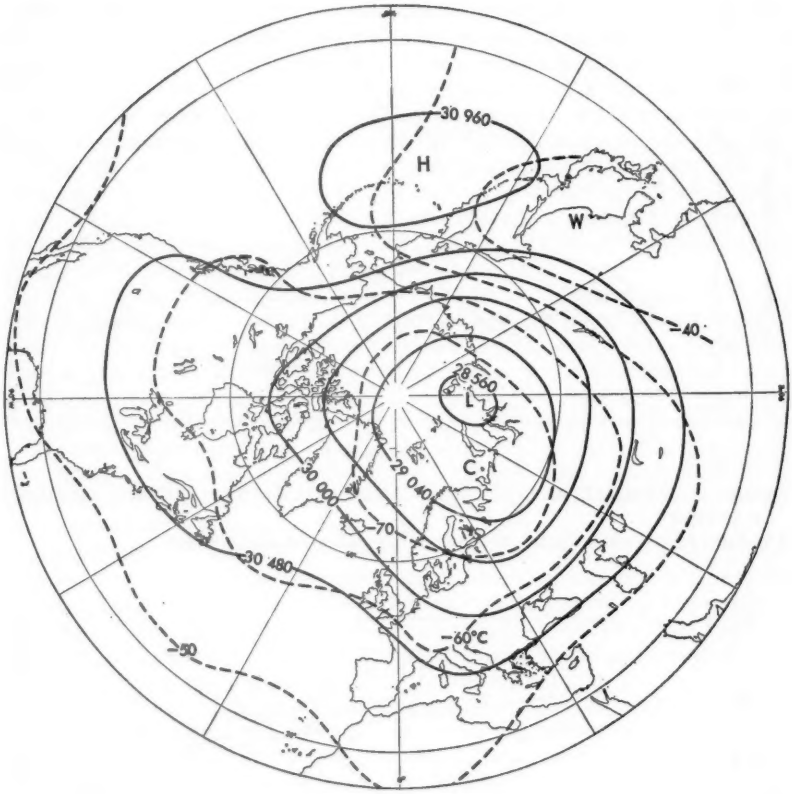

FIGURE 2—CHART FOR 10 MILLIBARS AT 00 GMT ON 2 DECEMBER 1974
——— contour heights at intervals of 480 gpm
– – – isotherms at intervals of 10 deg

the wind and temperature profiles are shown in Figure 4. The maximum wind speed of 173 m/s (≈335 kn) at 55 km (the mean between 54 and 56 km) is very near to the highest ever recorded over Scotland.

From 18 to 26 December the 10-mb vortex (28 300 gpm) near Novaya Zemlya and the Aleutian High (31 080 gpm) remained stationary and very strong north-westerly winds (≈150 kn) blew across the Canadian Arctic.

(c) *Mid-winter warming*

Just before Christmas the first signs of the warming appeared in the satellite data. Radiances in the B_{12} and B_{23} channels of the SCR showed maxima over Europe which moved eastwards with time. By 26 December the temperature increases at 10 mb reached minor warming proportions over China and south Siberia, and by 1 January 1975 the warmest air (−8°C) was located over central

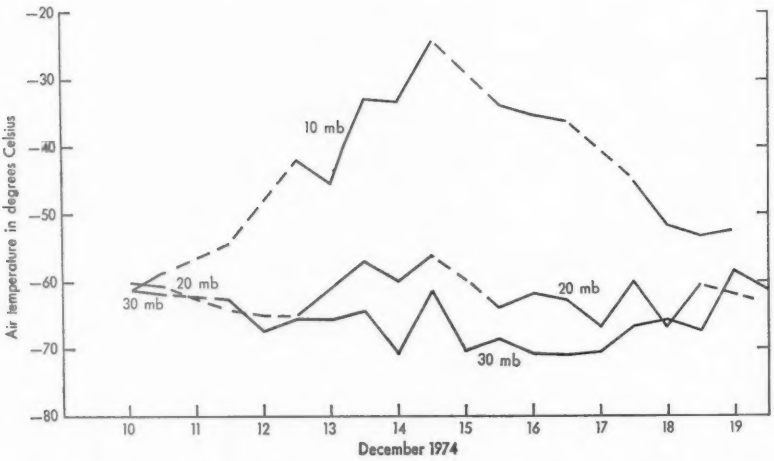

FIGURE 3—TEMPERATURE CHANGES AT VIENNA CAUSED BY MINOR STRATOSPHERIC WARMING
The dashed portions of the traces denote interpolation or extrapolation.

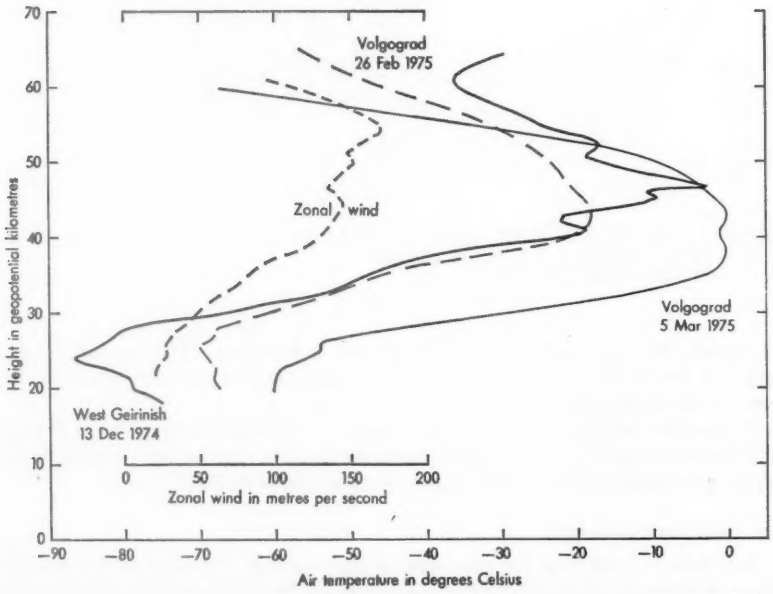

FIGURE 4—TEMPERATURE AND ZONAL WIND PROFILES AT WEST GEIRINISH ON 13 DECEMBER 1974, AND TEMPERATURE PROFILES AT VOLGOGRAD DURING AND AFTER THE FINAL WARMING

Siberia. The subsequent rise in contour heights over central and western Asia caused the vortex to weaken and move south-west to northern Sweden by 7 January. Between 1 and 7 January the warm air had moved north-eastwards to the Canadian Arctic, raising the 10-mb temperature over the North Pole to −28°C. The reversal of the meridional temperature gradient occurred by 3 January and the maximum temperature was located over the pole by 9 January.

Although the air over the Arctic then began to cool, warming still occurred over the Atlantic and Europe. Temperatures over central Europe rose from −72°C on 9 January to −55°C on 18 January, and a high cell (30 720 gpm) appeared over the central Atlantic. This cell moved eastwards across Europe and declined over Turkey by 24 January.

The pronounced wavenumber two pattern, which sometimes occurs shortly after warmings, showed up well on 20 January, with the European and Aleutian highs and two lows, one over Canada and the other over Siberia (Figure 5). Later in January the Siberian low declined into a trough, leaving the main vortex (28 800 gpm) over north Greenland. It is interesting to note that on 1 January the highest and lowest temperatures on the 10-mb chart were −15°C and −82°C, a difference of 67 deg. As a result of the warming, by the end of the month this difference had declined to 20 deg, i.e. −45 to −65°C. These temperature changes can be plainly seen in Figure 6 which shows cross-sections over the pole and along the Greenwich Meridian.

The effect of the warm air to the north was to reduce the westerly flow at 10 mb owing to the easterly thermal winds that were established. Although the 10-mb zonal wind at 60°N decreased by one-half in a week (29 December to 5 January (Figure 7)), it did not become easterly, so no 'major warming' occurred. However, a major warming did occur at 1 mb (48 km), where easterly winds were blowing to the north of 65°N by 2 January (Labitzke, 1975).

Early in February, further anticyclonic development over the United Kingdom and the Aleutians split the main vortex into two centres, over Hudson Bay and Siberia. The U.K. high collapsed by 11 February and allowed a strong westerly flow to spread across Europe. The Hudson Bay centre degenerated into a trough by 15 February and swept eastwards across the north Atlantic so that by 22 February one main symmetrical vortex remained near Heiss Island (80°N 58°E) and the mean zonal wind at 60°N reached the highest level of the winter (see Figure 7). By 25 February the temperature over Scandinavia had fallen to −70°C again but the satellite data showed warm air to be present high over central Russia.

(d) *The final warming (27 February–17 March)*

The first indication of the final warming was the development of a warm area (−40°C) over Manchuria at 10 mb on 24 February. This area moved north-west across the wind flow and became steadily warmer over the next few days. A minor warming alert was issued on 27 February for the area near 58°N 110°E. For the next two to three weeks the warmest air at 10 mb moved little from this position, reaching a maximum temperature of −5°C on 3 March. The warm air began to move north-eastwards from Siberia on 26 February and the first warm pulse reached the pole on 10 March. The warm air, spreading up to and over the pole, can be seen in Figure 8, which shows the time variations of the 10-mb temperatures on a section from 50°N 90°W to 50°N 90°E. In the middle of the warming the 10-mb temperatures over some areas of the Russian Arctic rose by

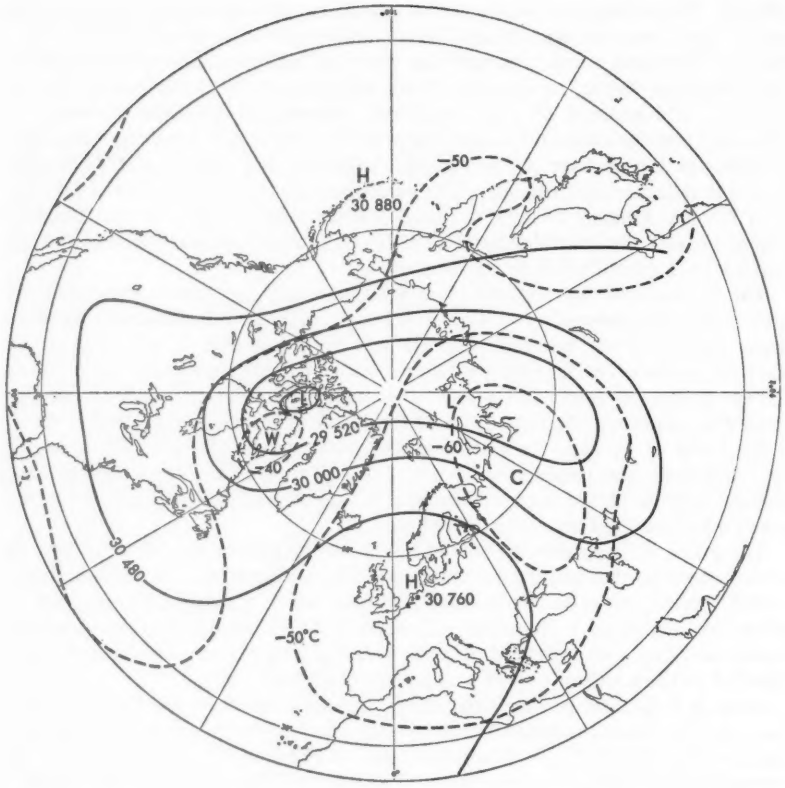

FIGURE 5—CHART FOR 10 MILLIBARS AT 00 GMT ON 20 JANUARY 1975
——— contour heights at intervals of 480 gpm
– – – isotherms at intervals of 10 deg

over 30 deg in a week. The 10-mb zonal mean temperatures during the final warming are shown in Figure 9. The meridional temperature gradient on 24 February was about 0·5 deg/degree of latitude at 70°N, by 6 March the temperature gradient was about zero, and then it became positive (i.e. a normal summer situation). Figure 10 shows two vertical temperature sections over the pole and through the Greenwich Meridian during and after the warming. Comparisons between these and sections for the mid-winter warming (Figure 6) are interesting. Although the initial conditions on both occasions were similar, the results were substantially different. The mid-winter warming produced an almost isothermal temperature field at 10 mb (≈30 km) but a cold polar core was maintained at 50 mb (≈20 km). The final warming, however, extended down throughout most of the polar stratosphere and produced a temperature section very similar to summer conditions. The extent of the warming in the upper stratosphere can be

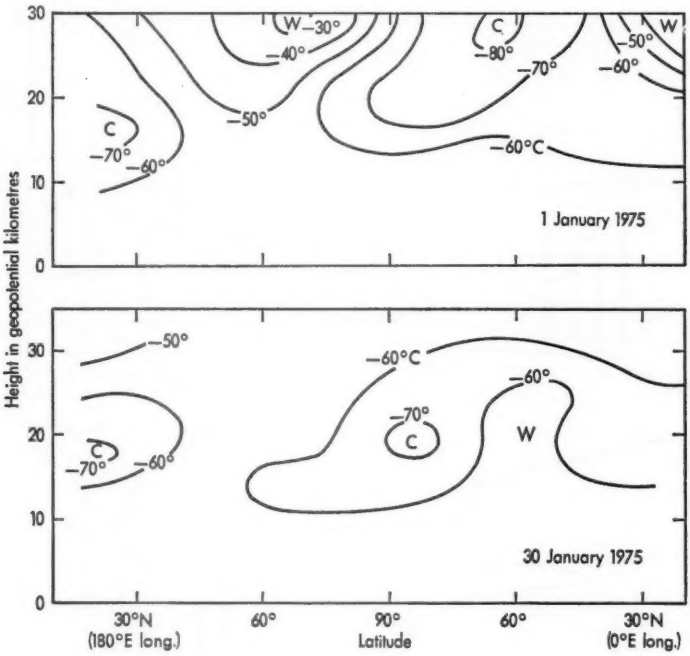

FIGURE 6—TEMPERATURES ON A LATITUDE–HEIGHT CROSS-SECTION ALONG THE 0°–180° MERIDIAN DURING AND AFTER THE MID-WINTER WARMING

seen in the temperature profiles from the rocketsonde observations at Volgograd (49°N 44°E) (Figure 4). Between 26 February and 5 March the air below 55 km became warmer (at 35 km by as much as 40 deg) as the stratopause descended to 40 km and increased in temperature to 0°C.

The final warming had the pattern of a simple wavenumber one type with the Aleutian high moving steadily northwards to the pole as the vortex filled and slipped southwards across Russia.

The effect on the geopotential heights between 28 February and 18 March is most striking (see Figures 11(a) and 11(b)). The main vortex (28 400 gpm) near 75°N 80°E began to fill and move westwards immediately the warm air appeared over China. The Aleutian high intensified and began to edge north-eastwards as the warm air moved across northern Alaska. By 16 March both the vortex (29 530 gpm) and high (31 300 gpm) were equidistant from the pole at 70°N, north-easterly winds at 30 mb were flowing over Scotland, and the zonal mean wind at 60°N had nearly turned to easterly (Figure 7). All three criteria have been used independently by workers in the past to define the final warming, but at present no official definition of the final warming exists. The sixteenth of March occurs in the 15th pentad of the year and according to Ebdon (1972) only once, in 1959, has the final warming occurred earlier.

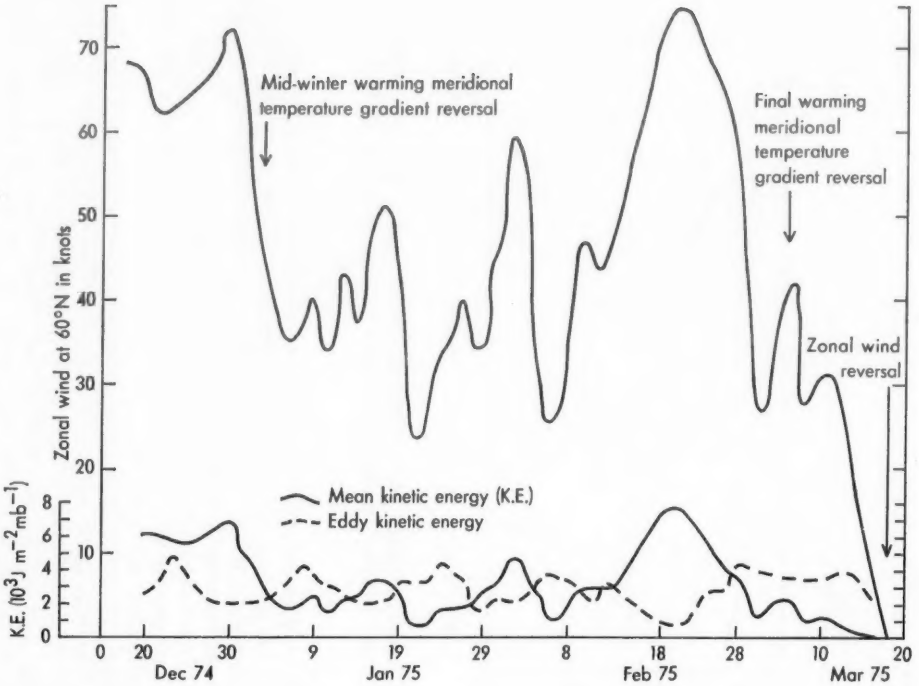

FIGURE 7—THE 10-MILLIBAR ZONAL WINDS AND KINETIC ENERGIES AT 60°N DURING THE 1974/75 WINTER

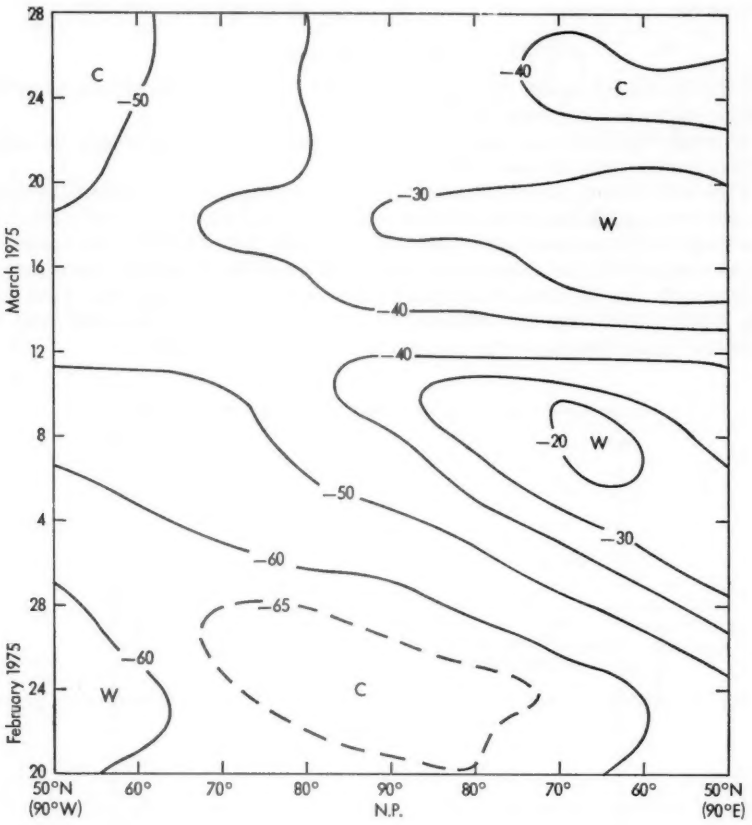

FIGURE 8—TEMPERATURE AT 10 MILLIBARS IN DEGREES CELSIUS IN SECTION OVER THE NORTH POLE DURING THE FINAL WARMING

By the end of March the high (31 450 gpm) was centred at 80°N 120°W and the low had filled to 30 300 gpm at 50°N 65°E. Air warmer than −45°C extended from central Asia across the pole to Greenland and the Canadian Arctic, and a strong mean easterly flow was present north of 60°N. The strong winds eased in mid April when the air over the polar cap cooled a little and did not increase again until May.

KINETIC ENERGY CHANGES DURING THE WINTER

During the winter, measurements were made daily of the mean and eddy kinetic energies (KE) at 60°N. The definitions of these terms are:

$$\text{mean KE} = \tfrac{1}{2}([u]^2 + [v]^2)\,(100/g) \quad \text{J m}^{-2}\,\text{mb}^{-1}$$

$$\text{eddy KE} = \tfrac{1}{2}(\overline{u^{*2}} + \overline{v^{*2}})\,(100/g) \quad \text{J m}^{-2}\,\text{mb}^{-1},$$

where the wind components at any point are given by

$$u = [u] + u^* \text{ and } v = [v] + v^*.$$

$[u]$ and $[v]$ are the zonal means, and u^* and v^* are the deviations from the means expressed in metres per second.

In general $[u] \gg [v]$ and for the average winter circulation at 10 mb, the mean KE is greater than the eddy KE.

However, during periods of stratospheric warmings, the increases in contour height over certain locations are substantial and they have the effect of increasing the local meridional wind speed and hence the eddy KE. Figure 7 also shows the mean and eddy KE at 10 mb at 60°N, plotted every day from mid December to late March. On the assumption that the conditions at 60°N represent those over the winter polar cap, the features of the winter, already discussed, can be detected in the changes in the mean and eddy kinetic energies.

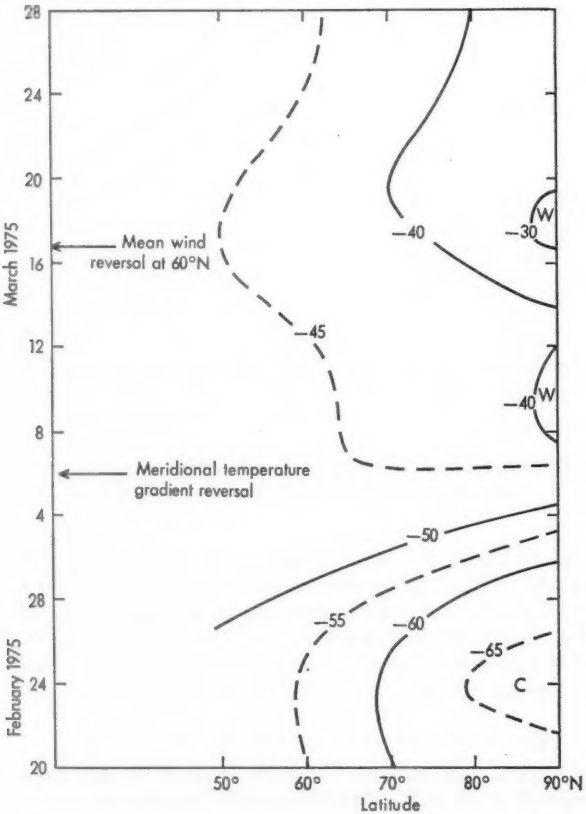

FIGURE 9—ZONAL MEAN TEMPERATURES AT 10 MILLIBARS IN DEGREES CELSIUS DURING THE FINAL WARMING

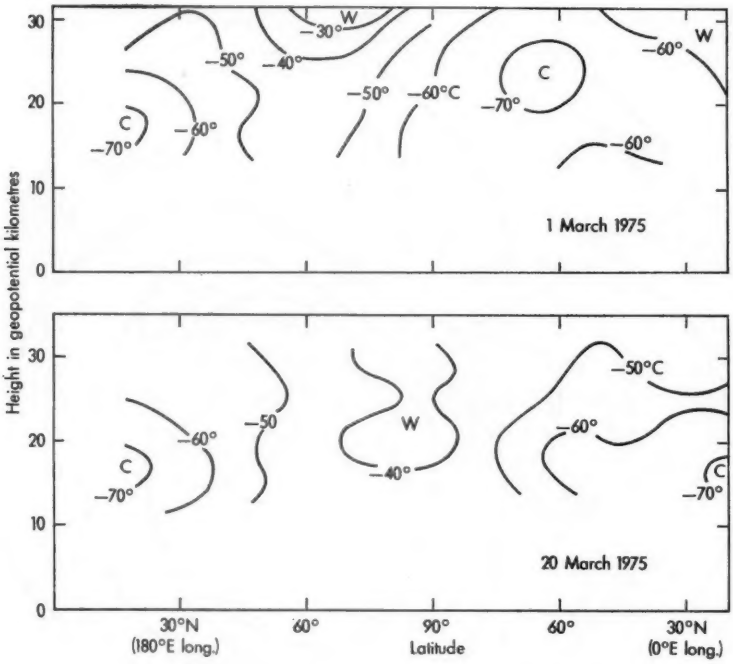

FIGURE 10—TEMPERATURE SECTIONS ACROSS THE NORTH POLE DURING AND AFTER THE FINAL WARMING OF 1975

During late December the mean KE built up to a maximum and then rapidly decreased during the period of the mid-winter warming. It then slowly increased to the highest of the winter (21–22 February) in a series of oscillations of increasing amplitude until finally there was a rapid loss of mean energy during the final warming.

The variation in the eddy KE is not as great as that of the mean, but it shows some marked periodicities and is generally out of phase with the mean KE. This is most apparent during January and February when the mean KE is increasing. A Fourier analysis of the eddy KE indicated a marked periodicity of about 15 days. This period has been noted before (Finger *et alii*, 1966 and Miller, 1967) with the suggestion that there was a lunar tidal effect influencing the stratospheric circulations.

Vertical velocity analyses

The fact that day-to-day changes in the temperature pattern are generally not great despite the large horizontal wind speeds implies that the air has a significant vertical motion over much of the winter hemisphere. In order to display the three-dimensional nature of the flow, isentropic analyses were carried out during the winter for the 350°C potential-temperature surface which lies between 20 and

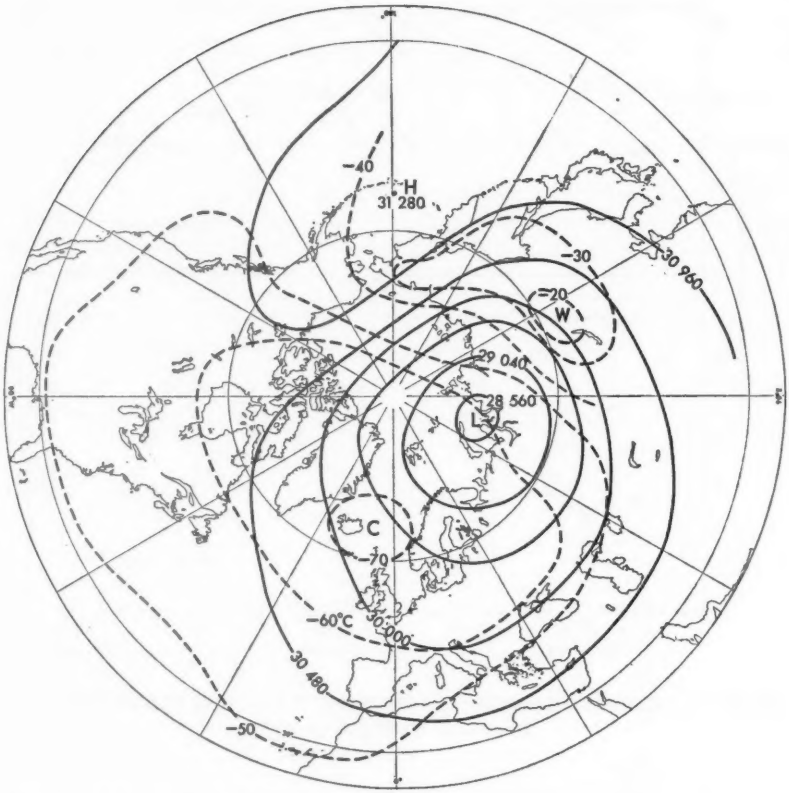

FIGURE 11(a)—CHART FOR 10 MILLIBARS AT 00 GMT ON 28 FEBRUARY 1975
——— contour heights at intervals of 480 gpm
– – – isotherms at intervals of 10 deg

30 mb. Figure 12 shows one such analysis for 28 February 1975, at the start of the final warming, on which streamlines and the height of the isentropic surfaces are drawn. The isentropic height field shows a high over the north-western Atlantic and a low over north-eastern Asia. The streamlines indicate that air passing near the centre of this low was displaced vertically by about 3 km, while ascending and moving over the pole to the North Atlantic. This ascent took about two days, while the descending air, moving more slowly over Europe and central Asia, took three days to return. During the descent into the Asian low, the air warmed up at the rate of about 15 deg per day, and it cooled at about 25 deg per day as it ascended over the pole. This cooling rate is at least an order of magnitude greater than can be expected by consideration of radiational cooling alone.

An estimate was made of the vertical velocities involved, on the assumption that the flow was adiabatic and that the general pattern did not change significantly from day to day. The main area of rising air on 28 February was located

FIGURE 11(b)—CHART FOR 10 MILLIBARS AT 00 GMT ON 18 MARCH 1975
——— contour heights at intervals of 480 gpm
– – – isotherms at intervals of 10 deg

to the north of Alaska with a maximum vertical velocity of about 4 cm/s, while the core of the descending air was over central Asia with a vertical velocity of −2·5 cm/s. It was found that the area north of 80°N was occupied entirely by ascending air. In fact, when zonal means of vertical velocity are calculated with corrections for the slight height-field changes with time, ascent is seen to have predominated north of about 65°N, with a maximum value of over 2 cm/s at the pole (Figure 13). This meridional profile during a warming is consistent with a two-cell structure described by Perry (1967) with ascent at low and high latitudes and descent in middle latitudes. Also shown in Figure 13 is a similar profile for 17 March when the final warming was well advanced and the vertical velocities were decreasing.

Conclusions

The new alert system worked well in the 1974/75 northern winter. High-level data were very useful in its application, since without these data the analyst had

FIGURE 12—ISENTROPIC ANALYSIS FOR THE SURFACE $\theta = 350$°C AT 00 GMT ON 28 FEBRUARY 1975
Solid lines represent streamlines. Broken lines represent the height of the surface in kilometres.

no knowledge of any warming until it reached radiosonde levels or had been intercepted by a rocketsonde. Access to satellite data is therefore a prerequisite of any useful stratospheric alert system.

Even though no major warming occurred below 10 mb, the 1974/75 winter contained many interesting features. The very early final warming, together with the westerly phase of the quasi-biennial oscillation have been shown by Ebdon (1975) to be important factors in determining the following summer's weather over south-east England. The hot, dry summer of 1975 certainly confirmed Ebdon's earlier suggestions.

Further study of the mid-winter and final warmings, especially of the vertical motions present in the atmosphere, is continuing.

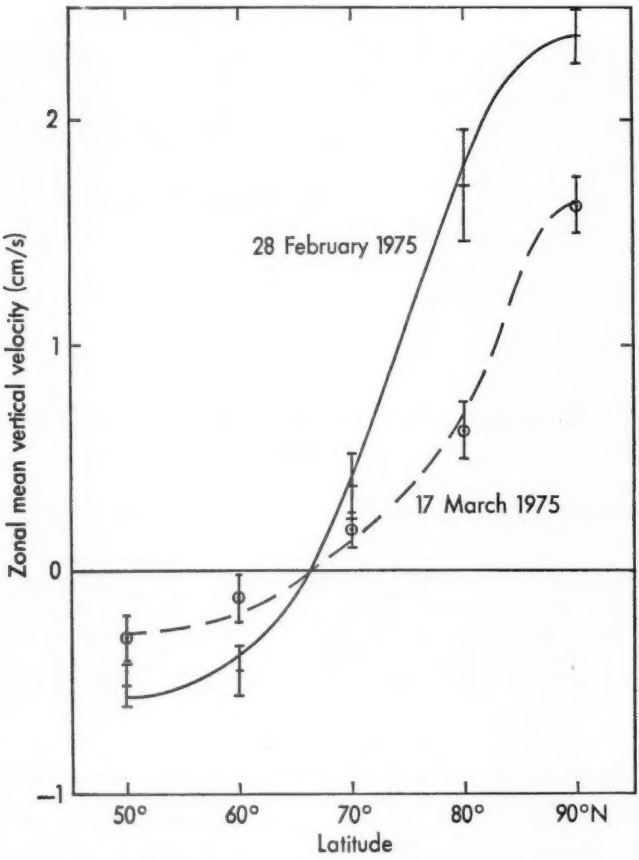

FIGURE 13—VARIATION OF ZONAL MEAN VERTICAL VELOCITY WITH LATITUDE
Standard errors of estimates are indicated by vertical lines.

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THE CURRENT WORK OF THE METEOROLOGICAL RESEARCH FLIGHT

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SUMMARY

It is now almost 10 years since Aanensen and Grant described the work of the Meteorological Research Flight (MRF) in the mid sixties. Since then there have been changes in staff, in aircraft, and in the research program of the unit, and this paper, a modification of that recently presented to the Atmospheric Environment Committee of the Aeronautical Research Council, attempts to bring the account up to date.

The paper briefly describes the two aircraft at present in use by the MRF together with their instrumentation, and the types of research program on which they have been and are being used.

INTRODUCTION

The Meteorological Research Flight (MRF) is a unit of the Meteorological Office established to conduct atmospheric research from aircraft. It forms part of the Directorate of Research and reports directly to the Deputy Director of Physical Research. The flight has been located at the Royal Aircraft Establishment (RAE) at Farnborough in Hampshire since 1946. RAE provide the maintenance crews for the aircraft and, needless to say, a vast amount of scientific expertise in aircraft instrumentation and operation. The aircraft are loaned to us by the Royal Air Force who also attach a unit of aircrew—at present three pilots, two navigators and two engineers—to fly the aircraft and to look after the operational side of the flight. The Royal Air Force also provide our buildings and allocate funds for their upkeep and improvement.

The civilian staff of the MRF, numbering about 25, are employed by the Meteorological Office. Only four of this number are 'first-grade' scientists; the remainder, forming the 'facilities' side of the flight, include workshop staff, electronics engineers and computer programmers. Most of the staff are expected to fly, total flying hours being in the region of 600–700 hours a year. As can be seen, there are not enough scientists at MRF to justify this amount of flying, and indeed most of our work is performed for outside users, chiefly the Cloud Physics Branch of the Meteorological Office, hereinafter referred to as the C.P.B.

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PLATE I—THE CANBERRA AIRCRAFT OF THE METEOROLOGICAL RESEARCH FLIGHT

PLATE II—THE HERCULES AIRCRAFT OF THE METEOROLOGICAL RESEARCH FLIGHT

PLATE III—PRESENTATION OF L. G. GROVES MEMORIAL PRIZES AND AWARDS, 14 NOVEMBER 1975

Left to right: Mr J. M. Nicholls, Dr R. J. Murgatroyd, Major K. G. Groves, Squadron Leader J. F. Narramore, and Corporal D. W. Roberts (see page 99).

PLATE IV—MAJOR K. G. GROVES WITH DR R. J. MURGATROYD, WINNER OF THE PRIZE FOR METEOROLOGY

(See page 99.)

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PLATE V—MAJOR K. G. GROVES AND AIR CHIEF MARSHAL SIR ANTHONY HEWARD WITH MR J. M. NICHOLLS, WINNER OF THE METEOROLOGICAL OBSERVER'S AWARD
(See page 100.)

PLATE VI—AWARDS TO CIVIL AIRLINE CAPTAINS AND NAVIGATORS
From left to right: Captain J. Vallance, Mrs J. Vallance, Director-General of the Meteorological Office, Mrs H. L. Chandor, Navigation Officer H. L. Chandor (see page 100).

Aircraft and instrumentation

At present we have two aircraft, a Canberra PR3 mainly for stratospheric research and a newly delivered Hercules—formerly a Lockheed C-130—primarily for research in the troposphere. Both aircraft have been substantially modified internally and externally, and much meteorological instrumentation has been fitted. This includes, on each aircraft, an advanced data-recording system by which samples can be obtained of up to 47 analogue and digital parameters at an overall sampling rate of 640 a second and recorded in 12-bit words on 1-inch magnetic tape. A PDP8/I computer located within the MRF building is used for transcribing the sequentially recorded airborne tape into a computer-compatible format. It is probably best to describe the aircraft one at a time.

Canberra WE 173 (Plate I)

This aircraft has a maximum endurance of about $3\frac{1}{2}$ hours and a ceiling of about 15 kilometres. As well as a pilot and navigator it can carry an MRF scientist sitting alongside the navigator. His function is to monitor and occasionally to control the output of the meteorological sensors as it is fed into the data-recording system. The major modification to the aircraft is the construction of a 15-ft nose probe so as to expose instruments sufficiently far ahead of the aircraft as to be in undisturbed air. A pitot and static-pressure system is carried at the tip of the boom together with wind vanes to determine angle of attack and angle of side-slip. Outputs from these vanes and the pitot–static system, used in conjunction with a stable platform—an ancient Ferranti FSP 100—enable us to determine horizontal and vertical gustiness.

Other major instrumentation of this aircraft consists of:

(a) *A sub-millimetric interferometer.* This instrument, developed by the National Physical Laboratory (NPL), covers the region from 8 to 40 cm^{-1} in which occur emission lines from several of the stratospheric trace gases. Although it is primarily intended for the measurement of high-level water vapour, estimates can also be obtained of the concentration of oxygen, ozone and the oxides of nitrogen. This equipment has only recently been brought into operational use and very few flights have been achieved so far.

(b) *A downward-facing radiometer.* This is a modified version of the Oxford University multi-channel radiometer currently being flown in the NIMBUS E satellite. The 12 channels employed in our version cover the wavelength interval from 3 μm to 50 μm in discrete intervals and also from 100 μm upwards and are used if possible in conjunction with satellite transits nearby.

(c) *An upward-facing radiometer.* This too is an instrument designed and constructed by the Department of Atmospheric Physics at the Clarendon Laboratory, Oxford. The instrument has three channels which measure radiation in the infra-red at about 12 μm, 50 μm and 100 μm respectively. Both these radiometers have been extensively test-flown and are now in operational use.

Other instrumentation in the Canberra includes a Rosemount thermometer, a manually operated Dobson–Brewer hygrometer and exposable filters for sampling particulates at high level, as well as the normal range of standard aircraft instruments.

Hercules XV 208 (Plate II)

This aircraft was delivered to us in January 1974, having been extensively modified since 1971 by Marshall's of Cambridge for its meteorological role. It has a ceiling of about 11 kilometres and a maximum endurance of more than 12 hours. It also has the ability to operate at low levels—below 150 metres, occasionally 30 metres over the sea—for more than 9 hours.

The major modifications consisted of:

(a) *The nose-boom.* A 22-ft nose-boom was constructed on which to expose pressure and temperature sensors together with pairs of wind vanes. The boom was built as an integral part of the aircraft to a rigorous specification of stiffness, and has a natural resonant frequency of about 15 Hz. At the base of the boom is housed a Ferranti stable platform with outputs to the navigator and to the data-recording system.

(b) *The repositioning of the radar.* In a basic C-130 aircraft the precipitation radar is located in the nose. Our nose-boom requires the radar to be located elsewhere, and consequently it has been sited in a pod situated near the centre line of the aircraft directly above the aircrew cabin.

(c) *A drop-sonde ejector.* One of the research projects at present being conducted by the C.P.B. involves the use of a drop-sonde. A suitable mechanism for ejecting these sondes has been designed and installed in the upper 'clam-shell' door at the rear of the aircraft. The design of the sonde and its ejection velocity are both critical in ensuring that it shall miss the aircraft tail after ejection. The aircraft is also fitted with a large storage area for up to 70 sondes of the type envisaged, namely a right circular cylinder about 110 cm long and 13 cm in diameter.

(d) *A recorder van.* The fuselage of a standard C-130 is very noisy—up to 115 decibels* in places—and is not conducive to lengthy periods of scientific endeavour. Rather than attempt to sound-proof the entire fuselage, it was decided to construct a transportable cabin or caravan, which would normally be anchored to the floor of the aircraft but which could be removed by fitting to it a set of wheels. The van has 10-cm thick glass-fibre walls enclosed in continuous metal sheets, and this construction renders the interior acoustically and electrically quiet. The van, roughly 4 m × 2 m × 2 m houses the data-recording system—essentially a precision tape recorder—and all the monitoring and control points of the meteorological sensors together with up to four scientists.

In the two front positions are situated the controls for the data-recording system, the Decca Navigator, the E290 radar—control of which can be passed by the navigator to the MRF scientists who can then program the elevation scan of the antenna; the radar output on a slave display in the van is photographed at 1-second intervals—and also controls for the opening and closing of the door for the downward-facing camera. In the front section of the van there are two television monitors which are linked to a pair of forward-facing TV cameras in the nose of the aircraft which provide the occupants of the van with a view of about 120° ahead of the aircraft.

*This noise level is measured relative to the conventional threshold value for the lowest level of audibility of 2×10^{-5} Pa.

The rear section of the van is separated by racking which extends across the centre of the van. This racking houses the data-recording system, the basic power packs, and a variety of displays and controls operated by the scientist seated at the back. The displays include digital indicators and also several paper-chart recorders which permit the continuous presentation of a selection of variables, e.g. air temperature, dew-point and sea surface temperature. The controls include the operation and calibration of the downward-facing radiometer, a Barnes ART4, which measures upwelling radiation in the 'window' region from 8 to 12 μm. The van is fitted with its own air-conditioning unit, originally designed for operation only on the ground, but soon to be modified to allow complete independence from the circulation system of the aircraft.

(e) *An air-sampling boom.* It is desirable to have a facility by which instruments can be exposed in flight and then be withdrawn into the cabin. For an aircraft with a pressurized fuselage it is necessary to design a scheme which will preserve the seals as far as possible and still allow some degree of flexibility in the type of instrument exposed. Our boom has been used for developing instruments and also on flights where a change of sampling-head—or of a particular part of the head—is necessary.

So much for the major conceptual and constructional changes which have been effected on the aircraft. Since the delivery of the aircraft in January 1974, most of our effort has been directed towards providing and testing suitable meteorological sensors. These include:

(a) Wind vanes mounted near the tip of the nose-boom to measure angles of attack and side-slip. Their deflexions can be measured with an accuracy of about 1·5 minutes of arc and can be recorded at a frequency of 40 a second.

(b) Rosemount thermometers which are also mounted on the nose-boom. Sensitive to about 0·1 deg, these too are recorded 40 times a second.

(c) A stable platform, a Ferranti Miniature Platform type B, is installed in the base of the boom. As with the Canberra, outputs from the platform can be combined with the vane data to give components of gustiness.

(d) A forward-facing 16-mm Telford camera, mounted on the cabin window between the first and second pilots. Operation of this camera is controlled from the van.

(e) An air-sampling pipe, 5 cm in diameter, which draws air into the fuselage and then, after a 1·2-m traverse, vents it out again. This pipe can be used for chemical sampling.

(f) Three independent instruments for the measurement of humidity. These are a Dobson–Brewer manual hygrometer, a Cambridge Systems automatic hygrometer—both of which measure frost-points—and a radio refractometer. This latter is mounted temporarily on an extensible boom.

(g) The boom has also been used to expose a Johnson–Williams liquid-water-content meter, and various types of carriers of filter papers from which samples of sulphates and SO_2 or freezing nuclei can be obtained.

(h) A downward-facing 35-mm Vinten camera, operated from the van.

(j) The downward-facing Barnes ART4 radiometer already mentioned.

As well as the above, arrangements are in hand for the mounting of a Knollenberg droplet spectrometer on one of the aircraft windows, and also the installation of an area for the testing, calibration, and signal-reception of drop-sondes.

Because of the difficulties encountered in the removal of sensing heads from the skin of a pressurized aircraft, it has been decided that major installations of equipment will take place in pods mounted below the wings. Three suitable pods—they are in fact jettisonable fuel tanks—and mounting pylons have been purchased and the wings have been suitably strengthened to take the extra load. The first of these pods will house a laser disdrometer, currently undergoing development in the C.P.B., which will make it possible to obtain holograms of cloud particles at a rate of one a second when necessary. A laboratory designed specifically to receive the pod and its laser has been constructed at the MRF building.

The research program

The research of the MRF is, of course, carried out under the general guidance of the Meteorological Research Committee (MRC). Annually a research program is prepared by the Chief Meteorological Officer, MRF for the forthcoming year, based on these recommendations, and approved by the Director of Research. As has been mentioned earlier, because of staff limitations, the actual scope of the research projects instigated within MRF is small, and largely confined to atmospheric dynamics; most of our flying, particularly with the Hercules, is on behalf of other branches of the Meteorological Office, especially the C.P.B., and for other national and international meteorological agencies.

The first part of the MRC program of research is concerned with instrumentation, and this occupies a large proportion of our effort. Most of this work has been mentioned in earlier sections above and will not be dealt with separately. The second and third parts of the MRC program deal with dynamical and physical investigations, but it is perhaps easier to define our physical-research projects with respect to the aircraft involved.

Physical research

(1) *Canberra*

(a) *Stratospheric composition.* The interferometer installed in this aircraft can give information about mixing ratios of various trace gases in the stratosphere. These include water vapour, ozone, and the oxides of nitrogen; ozone and water vapour are also measured directly by means of a Brewer Bubbler and a Dobson–Brewer manual frost-point hygrometer respectively. Our aim is to ascertain these mixing ratios on a regular basis and in a variety of meteorological situations in order to establish their mean values and variations therefrom. It is also possible—by banking the aircraft slightly—to obtain some information from the interferometer about the vertical variability of water vapour and ozone. This is an MRF-instigated project but of course follows on from, and is still closely related to, the work at the NPL.

(b) *Radiation from cirrus cloud.* The purpose of this project is to investigate the radiative properties of cirrus cloud in a number of discrete wavelength intervals in the hope of formulating techniques by which some of the properties of the clouds can be determined by remote sensing. The upward-facing radiometer has only three channels, which are at about 100 μm, 50 μm and 12 μm, but the downward-facing radiometer has many more channels in addition to

these three. One of the channels included is at about 3 μm, where absorption due to water vapour and CO_2 is strong, and is intended to measure solar radiation reflected from cirrus tops. The radiative properties of cirrus differ widely at the wavelengths chosen, and it is hoped that the differences can be related to number-density and to particle size. This project is controlled by the Department of Atmospheric Physics at the Clarendon Laboratory in Oxford.

(c) *The transparency of 'window' regions.* Considerable uncertainty exists at present concerning the transparency of the atmospheric 'windows' at 11 μm and 3·5 μm commonly used for the determination of sea surface temperatures from satellites. Indeed there is a significant discrepancy between the true and the derived equivalent black-body temperature. Much of this, it is thought, is due to the non-transparency of the 'windows', with the water-vapour dimer* playing an important role at 11 μm. Several channels are available in the downward-facing radiometer for the examination of the wavelength dependence of the dimer absorption. This project, too, is controlled by the group at Oxford. Recently the aircraft was detached to Dakar, Senegal in order to extend to tropical regions the above two projects.

(d) *Collection of atomic debris.* The Health Physics Division of the Atomic Energy Research Establishment at Harwell are interested in obtaining samples of any debris from atomic explosions which may be present near the tropopause. No special flights are arranged, but filters are exposed—usually one just below and one just above the tropopause—on an opportunity basis when another project calls for flights at these levels.

(2) *Hercules*

(a) *The structure of fronts (Project Scillonia).* The purpose of this project is the investigation of the distribution and intensity of frontal—and in particular warm-frontal—rainfall, and it involves the detailed three-dimensional analysis of a section of an active front both over the sea and over land. The project began in 1968 with experiments involving Doppler radars, the Varsity aircraft of MRF, and drop-sondes, and was located near the Isles of Scilly. This phase was completed in 1971, and subsequent analysis of the data was sufficiently encouraging to justify a second series of more ambitious experiments. In the interval since then, the Hercules has replaced the Varsity and the C.P.B., who control the project, have been developing a new drop-sonde with which to replace the self-opening radar targets which were dropped from the Varsity. The new sonde will incorporate the LOCATE system of positioning—and hence wind-finding—based on the LORAN-C navigation network, and will transmit its information to the aircraft for processing and recording. In this way, the project is made independent of ground-based radars (for sonde-tracking) and the full potential of the aircraft—its range, ceiling and precipitation radar—can be used to locate an active part of a front well away from land.

(b) *Orographic enhancement of rainfall.* The Meteorological Research Unit, a part of the C.P.B., which is located at the Royal Radar Establishment (RRE) at Malvern, is concerned with the use of radar in meteorological research. One of its projects is the investigation of the influence of the Welsh hills on the enhancement of rainfall in frontal situations. Early in 1975 they established a radar in west Dyfed to work on this project in conjunction with similar radars at

* Dimer: molecular species formed by union of two like molecules.

Defford. Our aircraft, the Varsity and Hercules, were used on suitable occasions to make vertical soundings near each of the two radar positions to measure the physical and dynamical properties of the cloud and its environment.

(c) *Convective cloud.* Before its disposal in April 1975, the Varsity aircraft, fitted with a field mill, conductivity probes and a cloud-droplet-charge detector, had carried out an investigation of the electrical properties of developing cumulus clouds. The data gathered in the course of this study are being examined by the C.P.B., who designed the instrumentation, and it is expected that similar instrumentation will be made for the Hercules. Even so, other parameters of cumulus clouds are to be investigated, in particular the number-density, size, composition and variability of cloud particulates, using both the Knollenberg disdrometer and laser holography.

(d) *The distribution of freezing nuclei in the atmosphere.* Some years ago a technique was developed by the C.P.B. for the determination of the number of freezing nuclei near the ground. This involved passing a known volume of air through a fine filter and then, by adjusting the temperature and degree of supersaturation in the chamber, allowing ice crystals to grow. They could then be counted with a microscope. A similar technique is being tried on the Hercules and first indications are that the modified method is successful. The program envisaged involves obtaining the vertical distribution of the nuclei on a regular basis and in a variety of meteorological situations.

(e) *The distribution of fluorocarbons in the atmosphere.* A simple scheme has been devised which makes it possible for samples of the outside air to be obtained, via the sampling pipe, in sealed containers the contents of which can then be analysed on the ground. The C.P.B., in conjunction with the Health Physics Division at Harwell, are co-operating in the determination of the fluorocarbon content of these samples.

(f) *Long-range transport of SO_2 in the atmosphere.* For the past few years we have been conducting flights, at first by the Varsity and later by the Hercules, over the North Sea in order to determine the amount of SO_2 being put into the atmosphere by the industrial areas of the United Kingdom and also the residual amount reaching the coast of Norway. The technique used consists of drawing a known volume of air through a series of filters which remove sulphates and SO_2 separately. (The source and trajectory of the air being known, an estimate of conversion rate can be obtained.) A sample is obtained every 20 minutes or so, and the flying is restricted to low levels and to those occasions when a broad south-westerly flow is limited by a good cloud-free inversion. Papers have been written on the instrumentation and the results by members of MRF, the Boundary Layer Branch of the Meteorological Office, and the Health Physics Division at Harwell (Aanensen and Grant, 1966; Johnson and Atkins, 1974 and 1975; Smith and Jeffrey, 1975).

(g) *Sea surface temperatures.* The ability of the Barnes radiometer to determine sea surface temperatures with sufficient accuracy—particularly relative accuracy—to be of use in oceanographic studies was demonstrated by Dr (now Professor) J. D. Woods in his experiments near Malta. More recently, the aircraft—at first the Varsity and then the Hercules—have made some measurements of sea surface temperatures for the Department of Oceanography of the

University College of North Wales, Bangor. These flights, always at low levels in order to minimize the correction for water vapour, have been confined to the Irish Sea, and were in association with ship observations being made at the same time. It should also be mentioned that extensive use was made of this facility in the recent GATE (GARP Atlantic Tropical Experiment) Project, in particular in the final phase of the experiment which was largely devoted to oceanographical observations.

(h) *Solar radiation.* In association with the Observational Requirements and Practices Branch, a program to measure the attenuation of solar radiation by clouds and the atmosphere has been prepared. We are, as yet, only in the early stages, namely obtaining and installing appropriate instrumentation.

Dynamical research

(a) *Mountain-induced momentum fluxes.* Since 1973 measurements have been made of the vertical flux of horizontal momentum ($\overline{\rho u'w'}$, where ρ is density and u' and w' are the perturbation horizontal and vertical components of air velocity respectively) in stably stratified flows over mountains. As in clear-air turbulence work, u' and w' are obtained at 20 Hz from the full gust equations (see Axford, 1968), which require inputs of the incidence of the airflow to the aircraft (measured by the angle-of-attack and side-slip vanes), the component of air velocity relative to and along the aircraft's longitudinal axis (measured by the experimental pitot–static system) and the altitude and velocity of the aircraft with respect to the ground (measured by instruments located in the inertial platform).

Twenty flights have been made over the Colorado Rockies in a collaborative project with the National Center for Atmospheric Research (NCAR), with the MRF Canberra operating in the stratosphere and one or two NCAR aircraft concurrently covering altitudes from the surface to the tropopause. Additionally about 10 flights have been made by the Canberra alone at heights of between 10 and 15 kilometres over the mountains of the United Kingdom, and three flights have been made by the Hercules in the troposphere over the mountains in Scandinavia. In all future flights on this MRF project it is planned to operate two MRF aircraft together to give good vertical resolution and coverage up to the lower stratosphere.

The purpose of the flights is to obtain quantitative estimates of the vertical-flux profiles in a variety of synoptic situations and over a variety of mountain ranges. Observed quantities can then be used as a check of the predictions of various theoretical models of mountain flow and induced fluxes (being developed mainly in the U.S.A.). If these models are satisfactory they can (if necessary) be incorporated in numerical global-circulation models. Lilly (1972) has shown for example that a downward flux of about 10^{-4} N/cm^2 (which would occur on about 10–20 occasions a year over the Rockies) below jet-stream level could cause an overestimation by about 15 per cent of the jet-stream speed, if not incorporated in numerical prediction models.

A secondary aim of these flights is to obtain measurements of fluxes and energy budgets (with an enhanced vertical resolution) near critical layers, the most easily identifiable of these being a zone of wind reversal above standing waves. Such layers, however, rarely occur within the height range of the Canberra.

On the flights made so far, several interesting flow patterns have been encountered, some being associated with moderate to severe turbulence and with difficulty in the handling of the aircraft. Figure 1 shows streamlines of airflow (as represented by isentropes) and horizontal wind speeds at Canberra flight levels on 18 January 1973 over the Rocky Mountains, and Figures 2 and 3 show the wind speed and temperature changes at a height of 10·9 km associated with the disturbance of double amplitude 1·2 km immediately over the highest peak. Fluctuations of about 90 kn (46 m/s) in the horizontal wind component, 20 kn (10 m/s) in the vertical component, and 13 deg in temperature, occurred in this disturbance. Patterns of flow which are similar to that shown in Figure 1, but of lesser amplitude (about 0·5 km) have been found over the Welsh mountains at 10·9 km.

(b) *Clear-air turbulence (CAT).* After an intensive period of clear-air turbulence research, culminating in the profitable collaborative work (see Browning *et alii*, 1973) with the MRU at RRE, Malvern in 1972 (which established that breaking Kelvin–Helmholtz waves were a source of clear-air turbulence experienced by an aircraft), there has been a lull in the MRF CAT research program. This was induced both by intensive effort on other high-level dynamical work (as in (a) above), and a lack of definition of *obvious* further fruitful avenues of investigation of the environment and formation of turbulence which can be followed up by a gust-research aircraft.

The current MRF program of research on turbulence is aimed at comparing turbulence spectra at sea away from gravity-wave input with those over land from the same portion of the jet stream, as well as assessing gravity-wave energy below and above turbulent zones over land; in other words it is directed at establishing whether gravity waves merely act as a trigger to CAT in shear zones below jet streams, or whether they supply energy as well.

A by-product of these flights would also be the securing of better data on the volume of atmosphere which is breaking down into turbulence in jet streams, since the flight plans (for the Hercules) include runs some 1100 km in length along the shear zone beneath the jet as well as frequent profiling sections across it. Estimates of the mean turbulent energy dissipation over a volume of atmosphere of synoptic dimensions are of importance in determining whether such effects should be included in forecasting models. Such estimates will also require better information on the volume of atmosphere filled by an individual group of Kelvin–Helmholtz waves and, as a separate exercise, we also hope to make flights to examine energy budgets and dimensions of individual wave groups on days when the waves are producing billow clouds. This work would be done by the Hercules only, but the gravity-wave work referred to earlier would involve both aircraft.

(c) *Low-level flow patterns near mountains.* A few low-level phenomena exist over the United Kingdom in stably stratified flows over mountains in which we have no or few measurements; two examples are the rare destructive surface winds to the lee of the Pennines and the associated lower tropospheric flow field, and rotor-streaming beneath a low-level reversal of wind (which may be another case of a critical-layer effect). Hercules flights will be made to investigate these phenomena when they occur—this too is an MRF project.

(d) *Fluxes near stratocumulus cloud.* Measurements of gross atmospheric conditions, and of the fluxes of heat, water vapour and momentum are being

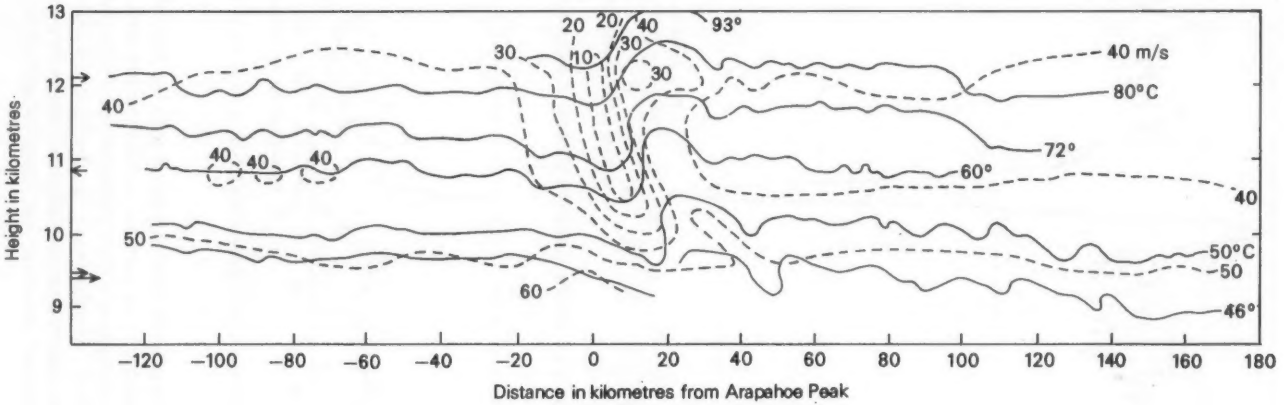

FIGURE 1—THE WIND AND POTENTIAL-TEMPERATURE FIELD MEASURED BY THE CANBERRA AIRCRAFT ABOVE THE COLORADO ROCKIES ON 18 JANUARY 1973

——— Potential temperature – – – – Westerly wind component

Arrows on the height axis indicate flight levels. The terrain beneath the flight pattern is rugged, with several peaks over 4 km from −120 to 0 km, after which it falls away to a 1·6-km plain beyond 20 km. The potential-temperature lines approximate to streamlines of airflow on this flight. 1 m/s ≈ 2 kn.

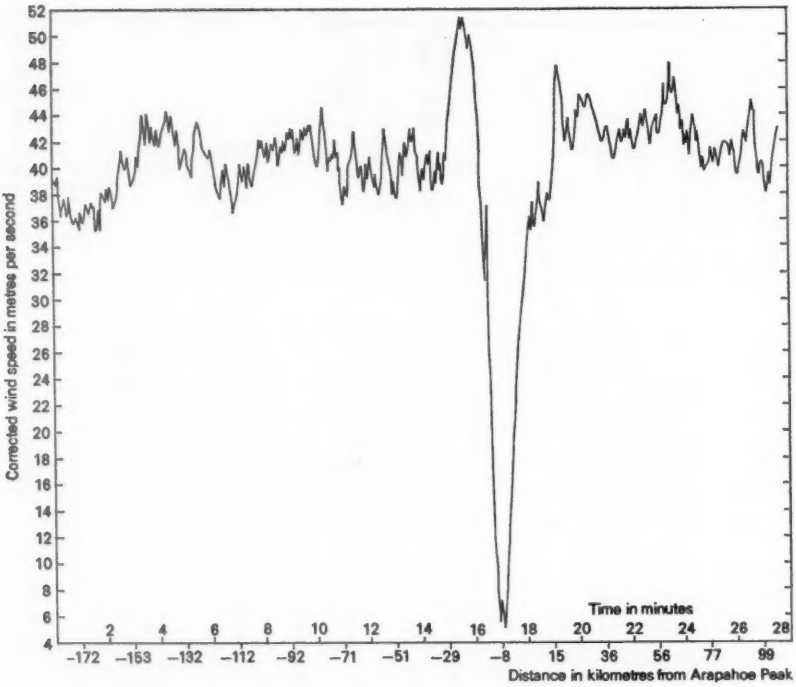

FIGURE 2(a)—HORIZONTAL WIND-VELOCITY COMPONENT FOR A RUN AT A HEIGHT OF 10·9 KILOMETRES

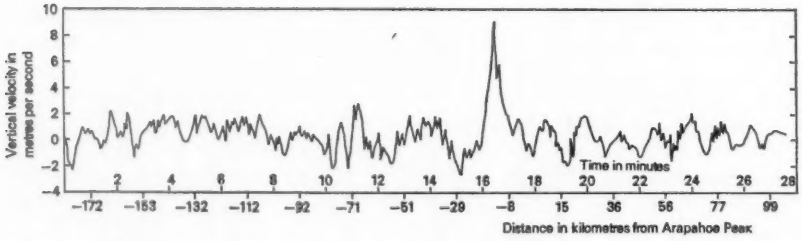

FIGURE 2(b)—VERTICAL WIND-VELOCITY COMPONENT FOR A RUN AT A HEIGHT OF 10·9 KILOMETRES

made above and beneath decks of stratocumulus cloud with the Hercules aircraft on this MRF project. Temperature and humidity perturbations used in the flux calculations are derived from a rapid-response platinum resistance thermometer and a refractometer respectively. Measurements are being made with a vertical resolution of about 50 metres and a time resolution of about two hours. The aim of the flights is to relate cloud structure and cloud behaviour to the fluxes measured.

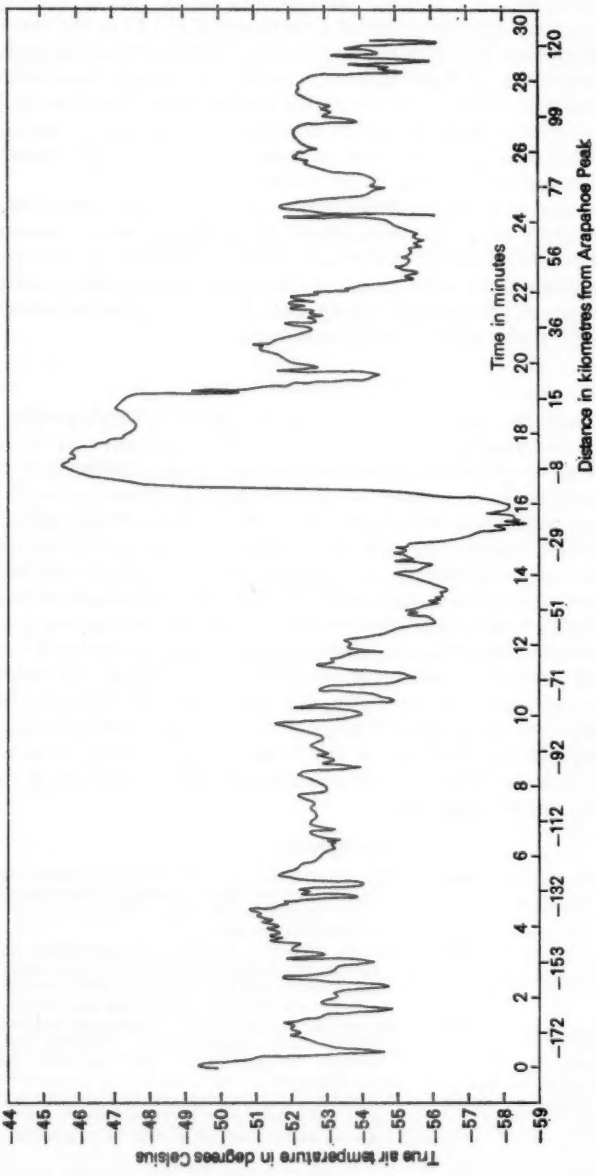

FIGURE 3—TEMPERATURE MEASURED ALONG THE RUN AT 10·9 KILOMETRES

(e) *Examination of the boundary layer over the sea.* The measurement of boundary-layer fluxes of heat, moisture and momentum over the tropical Atlantic formed the major part of the MRF contribution to the Global Atmospheric Research Programme Atlantic Tropical Experiment (GATE) in the summer of 1974. The Hercules was flown for over 350 hours at levels between 30 metres and 1600 metres on a variety of flight patterns in conditions ranging from completely calm and undisturbed (with low-level stability and no cloud) to extremely disturbed (under and in the base of tropical cumulonimbus clouds). Atmospheric convergence fields were also measured in areas of 6250 to 25 000 square kilometres in association with various cloud systems.

The measurement of boundary-layer fluxes over the sea continues to be a part of the MRF research program, the emphasis being placed on the measurement of the transfer of momentum from the atmospheric boundary layer to the sea in disturbed conditions (with wind speeds in excess of 30 kn (15 m/s), a situation in which ships cannot operate tethered balloons to make similar measurements. Several successful flights have already been made.

Conclusions

It is obvious from the foregoing account of the MRF research program that most of the work is aimed at fulfilling purely meteorological purposes. However, it is hoped that some of the research and of the data being gathered is of interest to other organizations, for example aircraft manufacturers, operators and certifiers; of particular interest may be the work on atmospheric pollution at stratospheric levels, high-level airflow over mountains, clear-air turbulence, and the composition of convective clouds (upon which icing criteria may depend). Two other points should be noted: firstly, data are recorded (but not analysed at MRF) in flight conditions which may be of direct interest to researchers in aeronautical sciences—for example, each landing produces a wind and temperature profile and low-level turbulence data on the magnetic tapes, and the profiles have good vertical resolution; secondly, it is hoped that all flight data will be available to any user, in the near future, in the form of computer-compatible tapes to be kept in the Archives of the Meteorological Office at Bracknell. Each tape will be documented and users could then perform any type of analysis that they desired on the flight data.

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LILLY, D. K. 1972 Wave momentum flux—a GARP problem. *Bull Amer Met Soc*, **53**, pp. 17–23.

ROACH, W. T. 1970 On the influence of synoptic development on the production of high level turbulence. *Q J R Met Soc*, **96**, pp. 413–429.

SMITH, F. B. and JEFFREY, G. H. 1975 Atmospheric transport of sulphur dioxide from the U.K. *Atmos Environ*, **9**, pp. 643–659.

AWARDS

L. G. Groves Memorial Prizes and Awards

The annual award of prizes took place on Friday 14 November 1975 at the Ministry of Defence, Whitehall. The Air Member for Supply and Organization, Air Chief Marshal Sir Anthony Heward, K.C.B., O.B.E., D.F.C., A.F.C., presided and the Prizes and Awards were presented by Major K. G. Groves, who was accompanied by Mrs Groves. The ceremony was attended by the Director-General of the Meteorological Office, Dr B. J. Mason, C.B., F.R.S. (See Plates III–V.)

The 1975 Aircraft Safety Prize was awarded to Squadron Leader J. F. Narramore, B.E.M., of Royal Air Force Laarbruch, with the following citation:

'With the advent of the axial-flow compressor in gas turbine aero engines, damage from foreign object ingestion has become a serious flight safety hazard, resulting in loss of life and the destruction of aircraft. It has been estimated that foreign object damage (FOD) now costs the Royal Air Force nearly twelve million pounds annually in aero-engine maintenance. In an attempt to reduce FOD at Royal Air Force station Laarbruch, Squadron Leader Narramore intensified the existing methods of FOD prevention, including research into the sources of foreign objects.

His initiation of a high-intensity airfield-sweeping programme produced good results, but he observed that the available sweepers did not adequately collect ferrous metal objects of the size and type known to cause most FOD. He therefore designed, and had built from available materials, a special electromagnetic sweeping machine; this has been a great success, as it is effective over both soft and hard surfaces and is particularly flexible and safe in use. It is now being considered for application throughout the Royal Air Force.

Squadron Leader Narramore's efforts have drastically reduced the extent of aero-engine FOD at Royal Air Force Laarbruch and he has clearly shown how this potential cause of accidents can be controlled in future. It is for this significant contribution to flight safety that he has been awarded the 1975 L. G. Groves Aircraft Safety Prize'.

The 1975 Meteorology Prize was awarded to Dr R. J. Murgatroyd, O.B.E., of the Meteorological Office, with the following citation:

'This prize is awarded to Dr Murgatroyd for his contributions to the study of the stratosphere, particularly in regard to the possibility of effects of supersonic aircraft on the ozone layer and climate. During the years 1972 to 1975, Dr Murgatroyd has led a team of investigators in the universities and government establishments and as a result of his efforts, a wide range of scientific expertise has been brought to bear on the complex problems of stratospheric dynamics

and photochemistry. Significant scientific advances have been made towards fuller understanding of phenomena as diverse as the sudden winter warming of the stratosphere and the photochemical balance of the ozone layer. In particular it has been demonstrated that the planned fleet of Concorde aircraft will have no significant effect on the climate or on the ozone layer.'

The Meteorological Observer's Award was awarded to Mr J. M. Nicholls, of the Meteorological Research Flight, with the following citation:

'This award is made to Mr Nicholls for his contributions to the observational programme of the Atlantic Tropical Experiment of the Global Atmospheric Research Programme (GATE) and more generally for his scientific exploitation of the observing capability of the Meteorological Research Flight. Mr Nicholls' efforts played a very large part in ensuring that the newly acquired Hercules aircraft was instrumented effectively and ready in time for this international (GATE) programme in which it played a key role. Mr Nicholls took part in a number of the long flights conducted during the experiment and played an active part in the international planning and co-ordination of the aircraft programme. In this respect his scientific insight was very important in ensuring an effective international programme appropriate to the scientific problems.'

The Second Memorial Award for 1975 was awarded to Corporal D. W. Roberts of Royal Air Force Ternhill, with the following citation:

'Gnome engine stall and rundown in RAF helicopters has long been a flight safety hazard, particularly in the single-engine Whirlwind, and has been the cause of a number of accidents. Over the last three years, Corporal Roberts has completed much valuable work that has resulted in an improved understanding of the cause of these engine failures and has led to the introduction of preventive measures. His latest investigations have produced more valuable information to help with achieving an ultimate understanding of this complex problem.

The efforts of Corporal Roberts are particularly commendable because, as a clerk statistics, he is not an engineering tradesman, yet he has completed outstanding work towards improving the integrity of the Gnome engine. For this significant contribution to flight safety he has been awarded the L. G. Groves Second Memorial Award.'

Meteorological Office awards to captains and navigators of civil airlines

Since 1954 the Director-General has made awards annually to encourage civil airline captains and navigators in making and transmitting airborne weather reports. Suitably inscribed books are awarded to aircrew members who have provided the best series of reports during the year. In addition captains who have given long and meritorious service in the provision of reports are considered for the award of brief-cases.

At a ceremony on 1 October 1975 at the Meteorological Office Headquarters the Director-General presented brief-cases to Captain J. Vallance, British Airways (Overseas Division) and to Navigation Officer H. L. Chandor, British Caledonian Airways (see Plate VI). This is the first time that a navigator has received the award of a brief-case, but because of the excellence of his reports over a long period it was decided, exceptionally, to make one of the awards to Mr Chandor.

REVIEWS

Methods in agricultural meteorology. Developments in atmospheric sciences, Volume 3, by L. P. Smith. 250 mm × 170 mm, pp. xii + 21, *illus.*, Elsevier Scientific Publishing Co., Amsterdam and New York, 1975. Price: Dfl. 75.

Even had this book been published anonymously, and without the very characteristic portrait which adorns the frontispiece, no one familiar with the style, approach and strong convictions of L. P. Smith could have the slightest doubt as to its provenance. Solidly down to earth but rarely if ever dull, often illuminating the subject with passing comments of deep insight, the author peppers his text with relevant quotations from world literature and shows himself a master of the graphic phrase which can make a diagram superfluous. (For example, the statement on page 68 that the shape of a particular graph 'resembles the track of a somewhat lofted drive at golf against a headwind'.).

The opening chapters are concerned respectively with the scope of agricultural meteorology and with the input data which are available on the meteorological and biological sides. Warnings of the imperfections and limitations of simple or derived weather parameters will be particularly useful to non-meteorologists. The next two chapters deal in turn with crops and farm animals in health and sickness; the sections here on plant and animal diseases are among the best in the book. Chapter 5 on soils, fertilizers and mulches is less impressive, largely perhaps because the complex processes involved have been difficult to quantify. Chapters 6 and 7 deal briefly but competently with such topics as irrigation, shelter, farm housing, storage and transport; and with weather forecasts for agriculture, and problems of frost and other meteorological hazards. The last chapter is made up of practical and helpful advice on how best the agrometeorologist might present his findings to different audiences in written or spoken form. Here the accumulated wisdom of a quarter century of communications experience—articles, books, public platforms, radio and television—has been distilled in a form which cannot but benefit young people and not only those in the field of agricultural meteorology.

There are two appendices. The first is an annotated list of the studies of agrometeorological subjects which have been published as WMO *Technical Notes*. This invaluable series has not yet received the attention it deserves outside meteorological circles and it was an excellent idea to afford it wider publicity. The second appendix is a catalogue of annotated bibliographies issued by the Commonwealth Agricultural Bureaux.

The content of the final appendix draws attention to the fact that the book, despite the generality of its title and that of the series in which it appears, is in fact virtually confined to British methods and experience, and is predominantly based on the work of the stalwart triumvirate of L. P. Smith, W. H. Hogg and R. W. Gloyne, with the backing mainly of G. W. Hurst, C. V. Smith and (honour to a non-meteorologist!) C. B. Ollerenshaw. At its best, the book draws strength from this in-breeding. Details are given of the pragmatic British approach to agrometeorological problems, aimed at developing practical rules of thumb which can be used to give operational advice to farmers. Timid students of agricultural meteorology will be encouraged by this forceful approach and

indeed by Mr Smith's caveat against unbecoming modesty caused by lack of knowledge: 'rest assured that other people probably know considerably less' (p. 148). Academic theorists may blanch in the face of what they may feel to be the wildly speculative models which are adopted in drawing up daily balance sheets of soil moisture (pp. 50–54) and elsewhere; the author's justification would be that the end results in practical application justify the apparently dubious means.

There is what appears to be a cry from the soul in the last sentence of the text, which advises potential writers of books: 'Don't . . . the writing of a book is sheer undiluted hard work'. Here and there throughout the present work there are hints of impatience in the writing. Sometimes it takes the form of an imprecision of language which is quite uncharacteristic of the author; e.g., (p. 50) 'it may be necessary to know the moisture content of the topmost layer of soil which contains the first 10 mm of soil moisture'. On rare occasions the author's vigorous style topples over into the intemperate. At a time when architects are belatedly discovering the help which meteorology can give them it seems indiscreet to accuse them of being 'scientifically illiterate' (p. 110). And in a book of predominantly British orientation it is surely a little unfair to dismiss grass-minimum temperature readings out of hand because grass does not grow freely in many parts of the world (p. 28). Some repetition is virtually unavoidable in a text of this kind but in places it seems excessive. Detail of little or no relevance, e.g. the list of areas not covered by artificial insemination centres in England and Wales (p. 100), might well have been pruned.

These minor criticisms of the book do not in any way dim one's satisfaction that, not for the first time, Mr. Smith has disregarded his own advice. At a time when the older generation of workers in this field are bowing out from the stage, he has poured the quintessence of his long experience into an excellent operational textbook which will be a valuable guide and source of inspiration to young agrometeorological students. Few experienced colleagues would disagree with his major theses, although some might wish to suspend judgement on particular techniques. The present reviewer takes serious exception only to one conclusion. The author refers to a reminiscence by Hilaire Belloc of a youthful indiscretion; the fact that the old man, all passion spent, was able to recall the wine but not the girl is curiously put forward by Mr Smith as a telling example of a correct sense of priorities. Luckily it is a case where the young student can confidently be relied upon to reach his own conclusions.

P. M. AUSTIN BOURKE

Readings on the climate of West Malaysia and Singapore, edited by Ooi Jin Bee and Chia Lin Sien. 255 mm × 195 mm, pp. x + 262, *illus.*, Oxford University Press, Oxford Books, 37 Dover Street, London W1X 4AH, 1974. Price: £10.

This collection of 19 published papers has been made for specialist and general readers variously concerned with the preservation of the environment and with services to the community. Publication dates range from 1954 to 1972 but two-thirds are post-1962.

The first of a set of four papers on synoptic meteorological topics is the well-known set of meticulously documented accounts of line-squalls (of airstream

boundary and Sumatra types) by I. E. M. Watts. The others are on north-east monsoon rainfall. K. Bryant's study of a wet December and a dry January at Singapore is followed by two papers by Gan Tong Liang. One examines large falls on the east coast of Malaya and derives three rules for forecasters. The second contains as Fig. 4.3c, a streamline analysis, at the 700-mb surface showing a large, anticlockwise circulation centred at the equator and labelled as a cyclonic vortex. Many analysts will object to this.

Of four papers of traditional climatology, two deal with sunshine and radiation, presenting many useful statistics, one summarizes temperature and humidity data and a short but interesting paper deals with Singapore's diurnal and seasonal cloudiness. Next come four papers on rainfall. I. E. M. Watts presents a mine of useful information on Singapore, excellently illustrated. Fourteen case studies contain series of half-hourly isohyetal maps and relevant upper-wind data. W. L. Dale has two papers on the rainfall of Malaya, ably exploiting the available data to help many potential users including forecasters. C. S. Ramage, on diurnal variation of rainfall, packs much valuable information into a few pages. This paper should be followed by a longer one using satellite data.

Writing on probable maximum 24-hour precipitation, J. G. Lockwood obtains estimates of 1000- and even 10 000-year falls from mainly short records; the latter are surprisingly lower than his probable maximum estimates and his use of hurricane depth–area relationships for Malayan rainfall is at least questionable. The Singapore floods of December 1969 are graphically described by Chia Lin Sien and Chang Kin Loon, but without any synoptic charts. S. Nieuwolt's study of evaporation and water balances is most interesting, but lacks Penman calculations. P. M. Stephenson's index of comfort should help those planning projects in Singapore, and Nieuwolt's short discussions on the city's micro-climate should have many useful applications.

M. Mansell-Moullin ably exploits scanty data to obtain probable maximum storm and flood estimates and an informative water balance and utilization paper rounds off the collection on a practical note.

The compilers have collected up and augmented the sets of references alphabetically and have numbered all figures and tables as one set. There are a few misprints. The periods of rainfall averages are important and should have been more clearly indicated and a year-by-year study of north-east monsoons would have strengthened the work. Several of the rainfall studies could now be updated to include many more station-years of data.

Meteorologists, hydrologists, civil engineers, agriculturists and many other professional people working in the region and in low latitudes elsewhere should find the collection a useful acquisition.

B. G. WALES-SMITH

PUBLICATIONS RECEIVED

The following have been received from the Meteorological Institute of the University of Thessaloniki:

Climatologika 6: *Air temperatures at the Larissa Institute for Forage Cultivations.* By G. Banoutsous and V. Semerdjidis. 1974.

Climatologika 7: *Programs for the processing of wind data by computers.* By Charalambos S. Sahsamanoglou. 1975.

Meteorologika 44: *Statistical processing of air temperature data from the city of Athens for the period* 1946–1973. By Angeliki Arseni-Papadimitriou. 1974.

Meteorologika 45: *Total ozone and temperature variations in the lower stratosphere and related teleconnections in the Mediterranean area.* By Christos Zerefos and Antony Bloutsos. 1974.

Université de Thessaloniki. Annuaire de l'Institut Météorologique et Climatologique, 43. Observations Météorologiques de Thessaloniki 1974, publiées par le Prof. Dr. G. C. Livadas, Thessaloniki, 1975.

HONOUR

The following honour was announced in the New Year's Honours List, 1976:

B.E.M.

Mr D. McC. McSween, Chief Cook, Ocean Weather Ship Base, Greenock.

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NOTICES

It is requested that all books for review and communications for the Editor be addressed to the Director-General Meteorological Office, London Road, Bracknell, Berkshire, RG12 2SZ, and marked 'For Meteorological Magazine'.

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